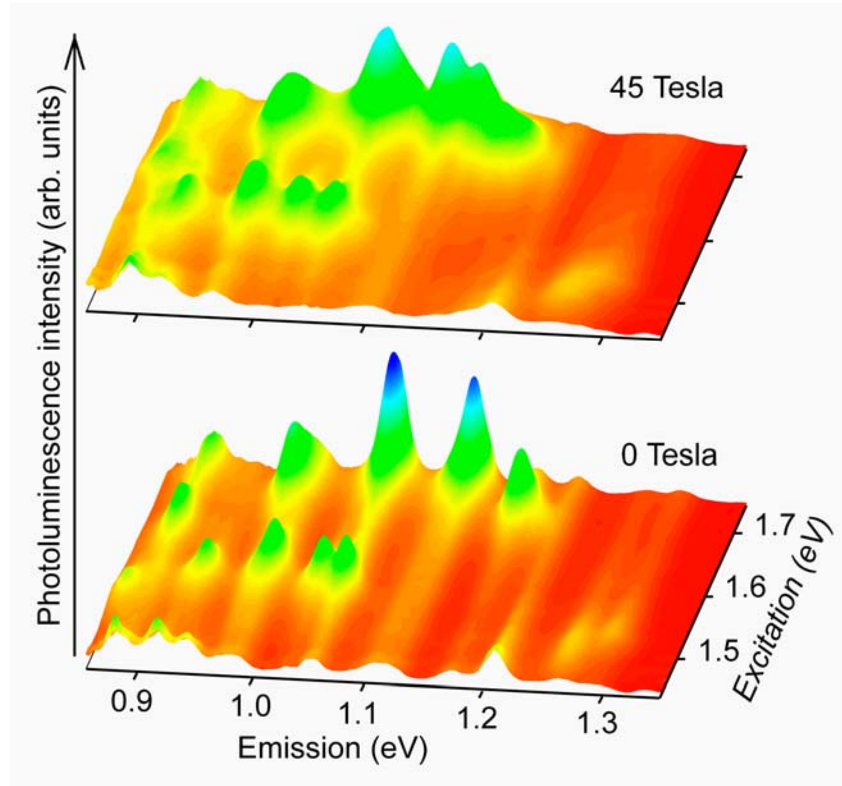
CAREER: Optical Spectroscopy of Quantum Coherence, Correlations, and Many-Body Effects in Nanostructures (Grant No. DMR-0134058) by J. Kono, Rice University

Single-walled carbon nanotubes are tubular crystals of carbon atoms that are just one atom thick. They come in different varieties, each with a subtle difference in structure and properties – some of them are metals and others are semiconductors.

Here we discovered that their basic electronic properties can change when they are placed inside a magnetic field. Specifically, the band gaps of semiconducting nanotubes shrank steadily with increasing magnetic field; in even stronger fields, we expect the gap to disappear altogether, causing the semiconducting nanotubes to transform into metals. This behavior is unique among known materials, but it is consistent with theoretical predictions based on the so-called Aharonov-Bohm effect.



Photoluminescence excitation spectroscopy data on individually-suspended single-walled carbon nanotubes at 45 T and 0 T. The field-dependence of the spectra contains evidence of the Aharonov-Bohm phase. See, S. Zaric *et al.*, Science **304**, 1129 (2004). See also the next slide for more details.

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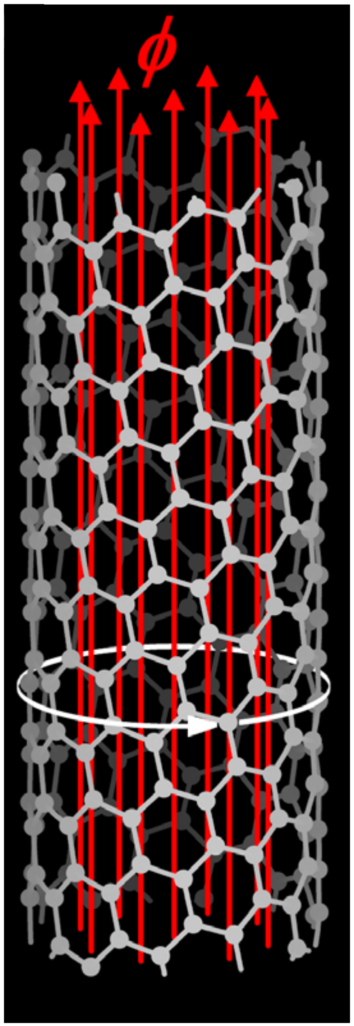
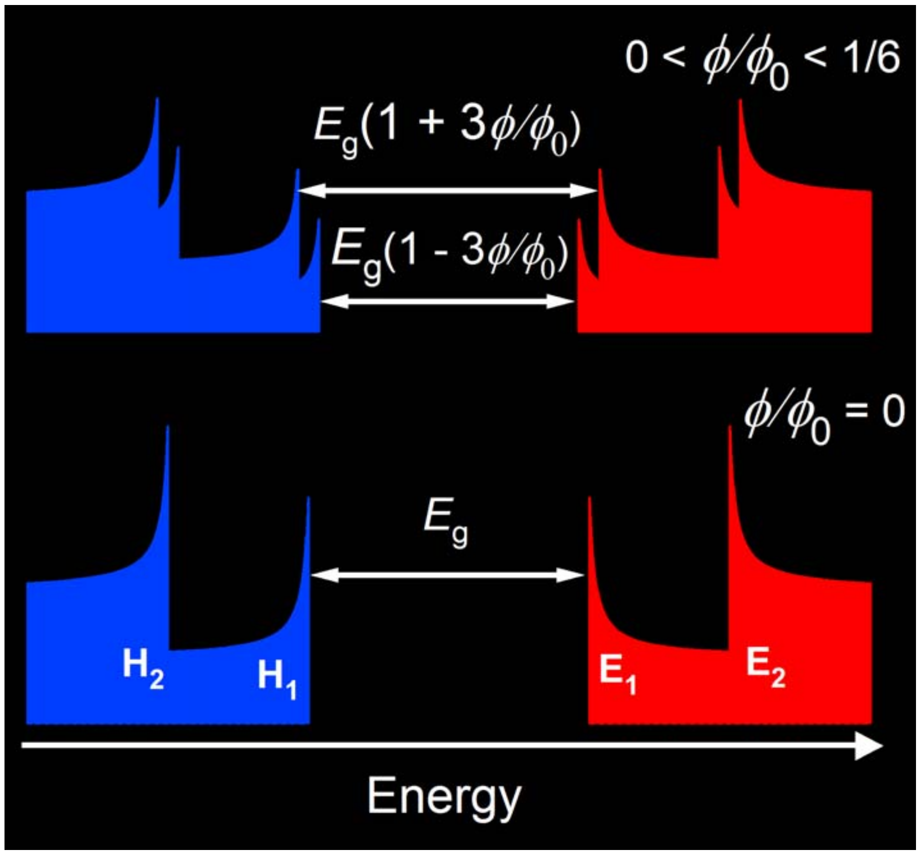
When a carbon nanotube is threaded by a magnetic flux ϕ …



Predictions by Ajiki and Ando more than 10 years ago:



S. Zaric *et al.*, Science **304**, 1129 (2004)

- Band structure depends on the **Aharonov-Bohm phase** $2\pi\phi/\phi_0$, where $\phi_0 = h/e$
- Band gap E_g of **semiconducting** nanotube continuously shrinks by $3E_g\phi/\phi_0$ → eventually becomes a **metal** when $E_g = 0$
- Each 1-D van Hove singularity peak **splits into two** by $6E_g\phi/\phi_0$

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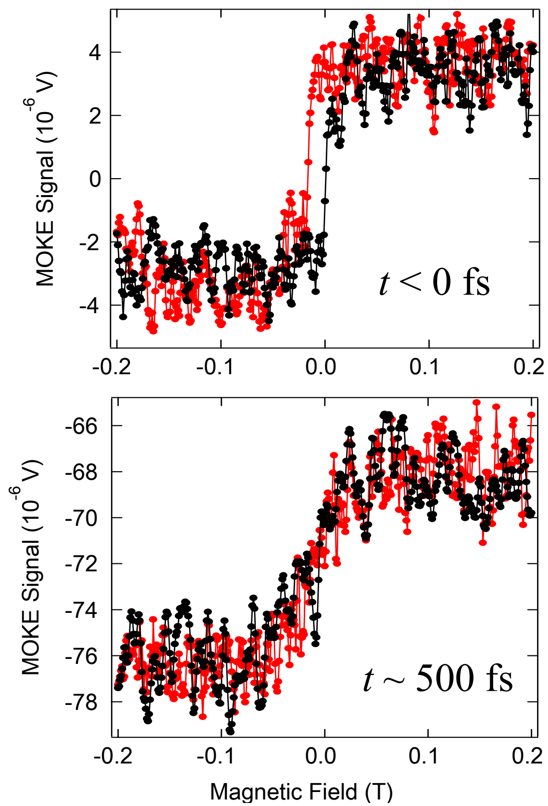
Ferromagnetic semiconductors are interesting materials, possessing the properties of magnets and semiconductors simultaneously. Their magnetism is controllable via adjusting the carrier density, and this makes them prime candidates for future *multifunctional devices*.

Here we discovered that their magnetic properties can change rapidly, in response to ultrashort pulses of light. Specifically, the so-called coercivity, which represents the 'hardness' of a magnet, shrank in the presence of laser-created photocarriers. This *laser-induced ultrafast softening* disappears as soon as the photo-created carriers recombine to disappear. This novel phenomenon opens up new possibilities for optically manipulating magnetism.



Ultrafast photo-induced softening, observed for ferromagnetic semiconductor InMnAs. It is seen that the coercivity (the width of the hysteresis loop) shrinks during the presence of photo-created carriers.

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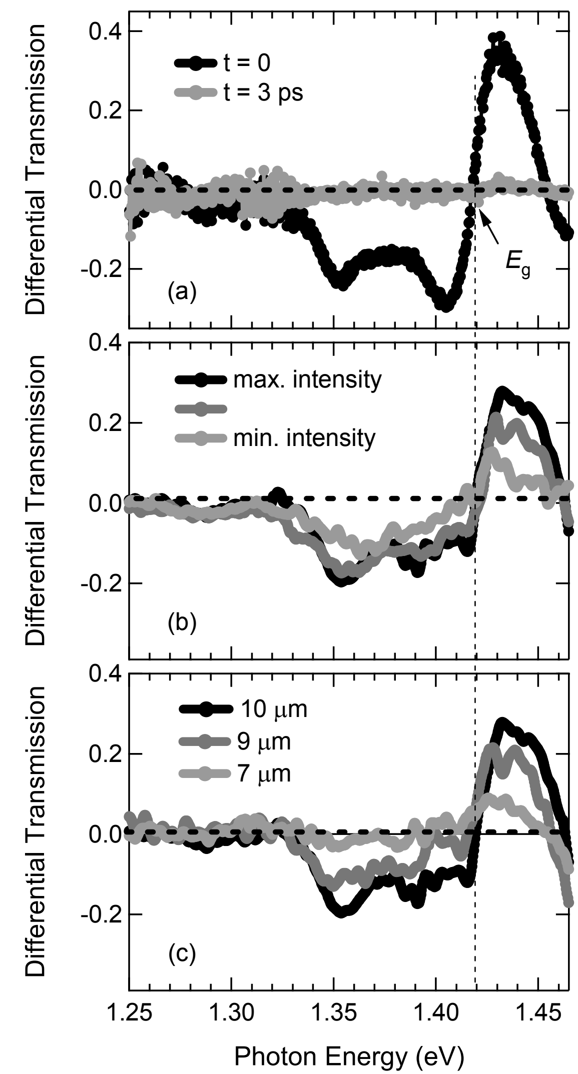
Under certain conditions, a normally opaque medium can be made transparent through coherent interaction with laser light. Such laser-induced transparency phenomena include self-induced transparency and electromagnetically induced transparency, which have been extensively studied in atomic and molecular systems, but not in solids due to unavoidable sample damage and/or short decoherence times.

Here, we demonstrate a new type of laser-induced transparency effect in semiconductors. Specifically, we observed ultrafast photoinduced transparency right above the band edge of GaAs at room temperature. The effect can be interpreted as a laser-induced blue shift of the band edge, whose amount is given by the so-called ponderomotive potential.



Observed photo-induced above-bandgap transparency in GaAs at room temperature.

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4 Rice undergraduates (Ben Schmid, Shanna Crankshaw, Derek Van Orden, Cliff Wong), 4 graduate students (Jigang Wang, Ajit Srivastava, Gordana Ostojic, Sasa Zaric), and 1 post-doc (Giti Khodaparast) have been involved in these experiments.

Both Ben and Shanna are currently graduate students at UC Berkeley, working in applied physics areas.

Jigang Wang has given two invited talks at prestigious international conferences based on these experiments. Giti Khodaparast has also given several invited talks and seminars, and she will become an assistant professor of physics at Virginia Tech in August 2004.

2 REU students (Mengning Liang and Ari Briskman) worked in the PI's group, as research assistants to graduate students, in Summer 2002. Mengning is currently a physics graduate student at the University of Illinois, Urbana-Champaign.

A female high-school student (Cherie Plouff) is currently working in the PI's group this summer.

The PI has developed a multi-disciplinary graduate course, "Topics in Quantum Semiconductor nanostructures." He is currently developing a senior-level undergraduate course, "Applied Quantum Mechanics."